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Revilla-León, Marta ; Gonzalez-Martín, Óscar ; Pérez López, Javier ; Sánchez-Rubio, José Luis ; Özcan, Mutlu

Abstract: PURPOSE To compare the accuracy of implant analog positions on complete edentulous maxillary casts made of either dental stone or additive manufactured polymers using a coordinate measuring machine (CMM). MATERIAL AND METHODS A completely edentulous maxillary model of a patient with 7 implant analogs was obtained. From this model, two types of casts were duplicated, namely conventional dental stone (CDS) using a custom tray impression technique after splinting (N = 5) and polymer cast using additive manufacturing based on the STL file generated. Polymer casts (N = 20; n = 5 per group) were fabricated using 4 different additive manufacturing technologies (multijet printing-MJP1, direct light processing-DLP, stereolithography-SLA, multijet printing-MJP2). CMM was used to measure the correct position of each implant, and distortion was calculated for each system at x-, y-, and z-axes. Measurements were repeated 3 times per specimen in each axis yielding a total of 546 measurements. Data were analyzed using ANOVA, Sheffé tests, and Bonferroni correction (= 0.05). RESULTS Compared to CMM, the mean distortion (m) ranged from 22.7 to 74.9, 23.4 to 49.1, and 11.0 to 85.8 in the x-, y-, and z-axes, respectively. CDS method (x-axis: 37.1; z-axis: 27.62) showed a significant difference compared to DLP on the x-axis (22.7) ($p = 0.037$) and to MJP1 on the z-axis (11.0) ($p = 0.003$). Regardless of the cast system, x-axes showed more distortion (42.6) compared to y- (34.6) and z-axes (35.97). Among additive manufacturing technologies, MJP2 presented the highest (64.3 ± 83.6), and MJP1 (21.57 ± 16.3) and DLP (27.07 ± 20.23) the lowest distortion, which was not significantly different from CDS (32.3 ± 22.73) ($p > 0.05$). CONCLUSION For the fabrication of the definitive casts for implant prostheses, one of the multijet printing systems and direct light processing additive manufacturing technologies showed similar results to conventional dental stone. CLINICAL SIGNIFICANCE Conventional dental stone casts could be accurately duplicated using some of the additive manufacturing technologies tested.

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Position Accuracy of Implant Analogs on the 3D Printed Polymer versus Conventional Dental Stone Casts Measured Using a Coordinate Measuring Machine

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Short title: *Accuracy of implant analogs on 3D printed models*

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Abstract

Purpose: This study compared the accuracy of implant analog positions on the complete edentulous maxillary casts either made of dental stone or additive manufactured polymers using a coordinate measuring machine (CMM).

Material and Methods: A complete edentulous maxillary model of a patient with 7 implant analogs was obtained. From this model, two types of casts were duplicated namely, conventional dental stone (CDS) using a custom tray impression technique after splinting (N=5) and polymer cast (PC) using additive manufacturing based on STL file generated. PCs (N=20; n=5 per group) were fabricated using 4 different additive manufacturing technologies (multijet printing-MJP1, direct light processing-DLP, stereolithography-SLA, multijet printing-MJP2). CMM was used to measure the correct position of each implant and distortion was calculated for each system at x, y and z-axes. Measurements were repeated 3 times per specimen in each axis yielding to a total of 546 measurements. Data were analyzed using ANOVA, Sheffe tests and Bonferroni correction (alpha=0.05).

Results: Compared to CMM, the mean distortion (μm) ranged from 22.65 to 74.86, 23.4 to 49.05 and 11.01 to 85.78 in the x, y and z-axes, respectively. CDS method (x-axis: 37.1; z-axis: 27.62) showed significant difference compared to DLP on the x-axis (22.65) ($p=0.037$) and to MJP1 on the z-axis (11.01) ($p=0.003$). Regardless of the cast system, x-axes showed more distortion (42.62) compared to y- (34.62) and z-axes (35.97). Among additive manufacturing technologies, MJP2 presented the highest (64.3±83.6), and MJP1 (21.57±16.3) and DLP (27.07±20.23) the lowest distortion being not significantly different from CDS (32.3±22.73) ($p>0.05$).

Conclusion: For the fabrication of the definitive casts for implant prosthesis, one of the multijet printing systems and direct light processing additive manufacturing technologies showed similar results to conventional dental stone.

Clinical Significance: Conventional dental stone casts could be accurately duplicated using some of the additive manufacturing technologies tested.

Keywords

3D printing; Additive manufacturing technologies; Direct light processing technology; Inject technology; Definitive implant cast; Implant prostheses; Multijet printing; Stereolitography technology.

Introduction

When fabricating implant prosthesis, a definitive cast should be an accurate representation of the 3-dimensional (3D) position of the implants in the patient's mouth.[1] Typically, this cast is obtained from a dental impression that is a negative imprint of the mouth.[2] When 4 or more implants are present, a splinting technique is recommended in order to obtain a more accurate working cast.[3-6]

The American Society for Testing and Materials (ASTM) has defined additive manufacturing (AM) as ‘‘a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies”.[7] The ASTM international committee F42 on AM technologies has determined seven AM categories: stereolithography (SLA), material jetting, material extrusion or fused deposition modelling (FDM), binder jetting, powder bed fusion (PBF), sheet lamination and direct energy deposition.[8] The growing development of AM technologies has allowed different applications in prosthetic dentistry.[9-11] The SLA and FDM technologies in particular, are the most common categories used for manufacturing dental models.[9-12] SLA technology is based on 3D CAD design that turns the polymer into a solid object through the repeated solidification of liquid resin through UV laser.[13-15] A different approach as an alternative to laser for UV polymerization of the material is the use of digital light projection (DLP) sources. In the DLP method, the silhouette of each layer is projected onto a surface of the resin that is polymerized by light either in the visible or the UV spectrum.[15,16] On the other hand, FDM technology builds parts layer-by-layer from bottom up by heating and extruding a thermoplastic filament from a printing nozzle. Once extruded into a bead, the material is immediately set at high temperatures of the machine and layered on a platform. The nozzle repeats the extruding and melting, layer by layer, until the object is complete.[17] The material jetting process is different in that a carriage jets photopolymers onto the workspace that are then polymerized using UV light. After a thin layer is created, the process repeats itself by jetting additional layers until the object is fully fabricated.[12,15,18]

The major conceptual difference between the 3D printed AM models and the conventional dental stone (CDS), is the design of the implant analogs. On the CDS models, the implant analog is designed as a retentive element so that it gets stuck and does not move when pouring the dental implant impression. Additionally, when manufacturing a 3D printed AM model, the digital implant analog is placed after the model is manufactured, and as a consequence, the digital implant analog design is retrievable from the cast.

The objectives of this study was to compare the accuracy of implant analog positions on the complete edentulous maxillary casts either made of dental stone or additive manufactured polymers using a coordinate measuring machine (CMM). The null hypothesis tested was that there would be no statistical significant difference between the model duplication methods at the x-, y- and z-axes.

Materials and Methods

Specimen preparation

One edentulous maxillary definitive cast of a patient was selected. The maxillary cast presented seven implant analogs (Tissue Level RN Straumann Implant analogs, Straumann, Basel, Switzerland) (Fig. 1). From this model, two types of casts were duplicated namely, conventional dental stone (CDS) using a custom tray impression technique after splinting (N=5) and polymer cast (PC) using additive manufacturing based on STL file generated. PCs (N=20; n=5 per group) were fabricated using 4 different additive manufacturing technologies (multijet printing-MJP1, direct light processing-DLP, stereolithography-SLA, multijet printing-MJP2). CMM was used to measure the correct position of each implant and distortion was calculated for each system at x, y and z-axes.

For the specimen fabrication in the CDS group, a conventional rigid splinting framework and a custom tray impression technique was employed.[19] The impression was poured with Type IV dental stone (GC Fujirock EP, GC, Tokyo, Japan) after mixing 22 ml water with 110 g dental stone under vacuum for 30 seconds. The cast was recovered after the dental stone had completely set (Fig. 2ab).

For the specimens of PC groups, a tactile (Renishaw DS10 Scanner, Renishaw, Gloucestershire, United Kingdom) and optical scanner (Renishaw DS20, Meditec, Gloucestershire, United Kingdom) with specific dental CAD software (Exocad GmbH, Hessen, Germany) was used to obtain the stereolitography (STL) file of the maxillary definitive cast. The same STL file was used to fabricate all other PCs using additive technologies for 4 different additive manufacturing technologies (multijet printing-MJP1, direct light processing-DLP, stereolithography-SLA, multijet printing-MJP2) (Table 1, Figs. 3a-d).

For all the PCs, the same digital implant analogs (Straumann RN ELOS implant analog, ELOS Medtech, Göteborg, Sweden) were used (Fig. 4).

Measurements

Each group contained 5 models, yielding to a total of 25 models having 7 implants each.

A coordinate measurement machine (CMM) was used to evaluate the position of the implant analogs on the x-, y- and z-axes. The position of the center point of all the implant replicas was measured with the CMM (Zeiss, Carl Zeiss Industrielle Messtechnik GmbH, Oberkochen, Germany) in an independent laboratory (Laboratorio de Ingieneria Dimensional S.L., Madrid, Spain). The measuring machine and procedures were similar as described earlier.[20] In brief, the master model was measured and used as a reference for comparison of the 25 different casts having implant analogs (Figs. 5a-b).

Prior to measuring, the definitive cast and the CDS and PCs were placed in a mold that was seated on a reinforced-concrete table. The CMM had a scanning head equipped with a 0.5 mm stylus that could be positioned anywhere within the working space of the CMM. In order to facilitate the measurement and to ensure the contact between the stylus and surfaces to be measured, a light force (0.1 N) was applied to the stylus. The data for each cylinder was condensed to a position to the center point of the cylinder in the x-, y-, and z- axes. The nominal linear accuracy of the machine was described by the manufacturer to be within 1 μm in all axes.[20] Three-dimensional (x-, y-, and z- axes) directions of displacement of the center points were calculated in μm in absolute values. The 3D position of the implant analogs of the definitive cast was used as a reference to calculate the discrepancy between all implant analogs on each model.

Statistical analysis

Statistical analysis was performed with SPSS Statistics for Windows Version 20 (SPSS, Chicago, IL, USA). Data (μm) were analyzed using ANOVA, Sheffe tests and Bonferroni correction (α=0.05).

Results

Compared to CMM, the mean distortion (μm) ranged from 22.65 to 74.86, 23.4 to 49.05 and 11.01 to 85.78 in the x, y and z-axis, respectively (Table 2).

CDS method (x-axis: 37.1; z-axis: 27.62) showed significant difference compared to DLP on the x-axis (22.65) (p=0.037) and to MJP1 on the z-axis (11.01) (p=0.003) (Table 3).

Regardless of the cast system, x-axis showed more distortion (42.62) compared to y- (34.62) and z-axis (35.97). Among additive manufacturing technologies MJP2 showed the highest (64.3±83.6), and MJP1 (21.57±16.3) and DLP (27.07±20.23) the lowest distortion being not significantly different from CDS (32.3±22.73) (p>0.05).

Discussion

This study analyzed the accuracy of the implant analogs on casts obtained from conventional procedures where the impression was made using polyether followed by establishing the splint and fabricating the custom tray for complete arch implant impression. The casts were duplicated using different additive manufacturing technologies and accuracy was compared to dental stone using CMM. Based on the results of the present study, since there were significant differences between systems on x- and z-axis, the null hypothesis could be rejected.

The CMM analysis is widely used in dentistry in order to calculate the implant analog position on the x, y and z-axes, which is considered an accurate method to assess the dimensional discrepancies of the implant analog position between the different dental models.[21,22] Previous studies have analyzed the accuracy and precision of the AM technologies, most of which were focused on the treatment planning and diagnosis for oral and maxillofacial surgery and orthodontics.[23-32] However, to the best knowledge of the authors, there is no published study to date that analyzed the accuracy of the digital implant analog position on a 3D AM cast. When duplicating a cast with conventional procedures, the mean distortion was 37.1 (27.80), 32.13 (21.69) and 27.62 (23.72) μm while for the AM casts it was 44 (39.25), 35.24 (26.26) and 38.05 (48.03) μm for the x-, y- and z-axis, respectively. Yet, only 2 of the 4 technologies showed no significant difference on the x, y and z-axis compared to the control group. Hence, based on the results obtained, it could be stated that the duplication of a master cast with AM technologies based on MJP1 and DLP could show similar distortion compared to CDS.

On the z-axis MJP1 method showed significantly better results compared to the CDS method. Interestingly, although, MJP1 and MJP2 methods were based on the same multijet printing technology with a layer thickness of 35 μm and the latter had a better resolution, the accuracy results were more favourable with the MJP1 on the z-axes. On the other hand, compared to the CDS method, DLP method presented significantly lower distortion on the x-axes although the layer thickness with 50 μm being slightly higher than those of MJP1, MJP2 and SLA. These results could be attributed to multiple variables such as building orientation, intensity power of the polymerization UV light source and post processing procedures. Nevertheless, among all additive manufacturing technologies, MJP2 showed the highest standard deviations up to 135 μm compared to those of other systems (DLP: 30.2; SLA: 37.9). The conventional CDS system in turn, demonstrated mean (37.1) and standard deviations (23.7) less than 35 μm in all x-, y- and z-axis, indicating that meticulous handling of Type IV dental stone may also deliver acceptable accuracy.

For the specimen fabrication of the CDS group, the conventional procedures selected to duplicate the master cast have been demonstrated to be accurate and represents the clinical procedures needed to make a complete arch impression of multiple implants.[19,21,33,34] For manufacturing the PCs, master cast was digitized using a specific tactile dental scanner and the same STL file was used to fabricate all the

PCs. In this study, different manufacturing technologies were compared that employed various processing parameters and post-processing procedures that were previously shown to affect the accuracy and repeatability outcomes.[35] However, these results were obtained from standard geometric shapes where implant related parameters were not studied.

One important factor that could influence the accuracy of the printed polymer is the layer building orientation of the 3D object. In a previous report, it was demonstrated that the building orientation of the 3D printed object influences the mechanical properties where vertically printed specimens with the layer oriented perpendicular to the load direction exhibited a higher compressive strength than material printed horizontally.[36] When manufacturing an AM cast for a complete-arch implant prostheses, the accuracy of the housing of the digital implant analog of the cast would determine the accuracy of the implant analog position on the cast. Currently, digital implant analogs show variations in design depending on the brand. For the present study, one digital implant analog brand was selected and the digital implant analogs used were always in the same position for all measurements. As a definitive cast, a real patient case was selected without taking the angulation, depth and distance between the implants into consideration that needs further investigation. Similarly, the number of implants, retention and stability on the 3D printed PCs could further affect the results.

The incorporation of additive manufacturing technologies enables to duplicate a definitive cast where implant analogs could be easily reused or replaced when damaged. Furthermore, STL files of the definitive casts of the patients could be stored in the cloud in its corresponding physical space.

Conclusions

For the duplication of the definitive casts for implant prosthesis, one of the multijet printing systems and direct light processing additive manufacturing technologies tested showed similar accuracy compared to the models obtained using conventional dental stone.

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Conflict of interest

The authors did not have any conflict of interest in any of the materials used in this study.

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Captions to tables and legends:

Tables:

Table 1. Summary of manufacturers and technical details of cast fabrication.

Table 2. Mean values for distortion (μm**)**, standard deviations and confidence intervals of each group at x-, y- and z-axis.

Table 3. Multiple comparisons for the x-, y- and z-axis between the experimental groups according to Bonferroni correction (alpha=0.05).

Figures:

Figure 1 Complete edentulous maxillary definitive cast with 7 implant analogs.

Figures 2a-c. a) Printed metal splint on the definitive cast, **b)** printed polymer custom tray on the definitive cast, **c)** conventional dental stone cast obtained duplicating the definitive cast through conventional impression technique.

Figures 3a-d. 3D printed model using **a)** MJP1, **b)** DLP, **c)** SLA, **d)** MJP2 additive technologies. For group abbreviations see Table 1.

Figures 4a-c. a) Apical view of the digital implant analog, **b)** Coronal view of the digital implant analog, **c)** Screwdriver to hold and position the implant analog on the printed cast.

Figures 5a-b. a) Analysis of the implant analog position on the x-, y- and z-axis using a CMM machine, **b)** Best fit calculation using the specific software.

Figures 6a-d. Closer view of the surface texture of a specimen manufactured using **a)** MJP1, **b)** DLP, **c)** SLA, **d)** MJP2.

Tables:

Groups	CDS	MJP1	DLP	SLA	MJP2
Printer (Manufacturer)		Projet 3510MP (3D systems, South Carolina, USA)	Prodways ProMaker D35 (Dreve, Unna, Gernany)	Infinident (Sirona, Bensheim, Germany)	Object (Stratasys, Eden Prairie, Minn, USA)
Technology	Conventional Type IV Dental Stone (GC, Fujirock EP, Tokyo, Japan) Impression with polyether, splinting, custom tray	Mutlijet printing	Direct light processing	Stereolithography	Multijet printing
Layer thickness (µm)	-	35	50	50-100	35
Resolution (x-, y-, z-axis)	-	HDX: 375x450x790 DPI	784x784x1016 DPI	-	HQ: 600x600x1600 DPI

Table 1. Summary of manufacturers and technical details of cast fabrication.

Axes	Groups	N	Mean (µm)	Standard deviation	Confidence interval (95%)	
					Lower bound	Upper bound
X	CDS	35	37.1	22.8	29.3	44.9
	MJP1	35	23.6	21.2	16.3	30.8
	DLP	35	22.7	17.1	16.8	28.5
	SLA	35	54.9	37.1	42.2	67.7
	MJP2	35	74.9	81.7	46.8	102.9
	Total	175	42.6	47.1	35.6	49.7
Y	CDS	35	32.2	21.7	24.7	39.6
	MJP1	35	30.1	19.2	23.6	36.7
	DLP	35	23.4	13.4	18.8	28.1
	SLA	35	49.1	37.9	36.0	62.1
	MJP2	35	38.4	34.1	26.7	50.1
	Total	175	34.7	27.9	30.5	38.8
Z	CDS	35	27.6	23.7	19.5	35.8
	MJP1	35	11.0	8.5	8.1	13.9
	DLP	35	35.1	30.2	24.7	45.5
	SLA	35	20.3	18.4	13.9	26.7
	MJP2	35	85.8	135	39.4	132.2
	Total	175	35.9	67.9	25.8	46.1

Table 2. Mean values for distortion (μm**)**, standard deviations and confidence intervals of each group at x-, y- and z-axis.

AXIS	Groups		Differences of means (μm)	*P* value
X	CDS	MJP1	13.543	0.113
		DLP	14.457	*0.037
		SLA	-17.838	0.165
		MJP2	-37.752	0.110
Y	CDS	MJP1	1.990	1.000
		DLP	8.733	0.375
		SLA	-16.914	0.222
		MJP2	-6.238	0.987
Z	CDS	MJP1	16.610	*0.003
		DLP	-7.476	0.938
		SLA	7.295	0.801
		MJP2	-58.162	0.148

Table 3. Multiple comparisons for the x-, y- and z-axis between the experimental groups according to Bonferroni correction (alpha=0.05).

Figures:

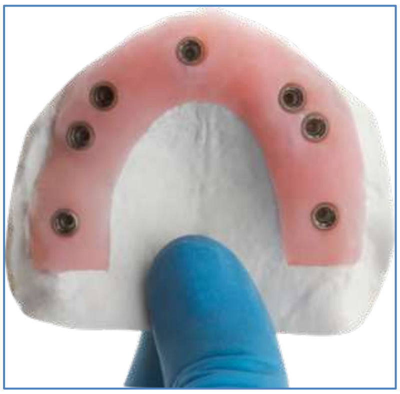
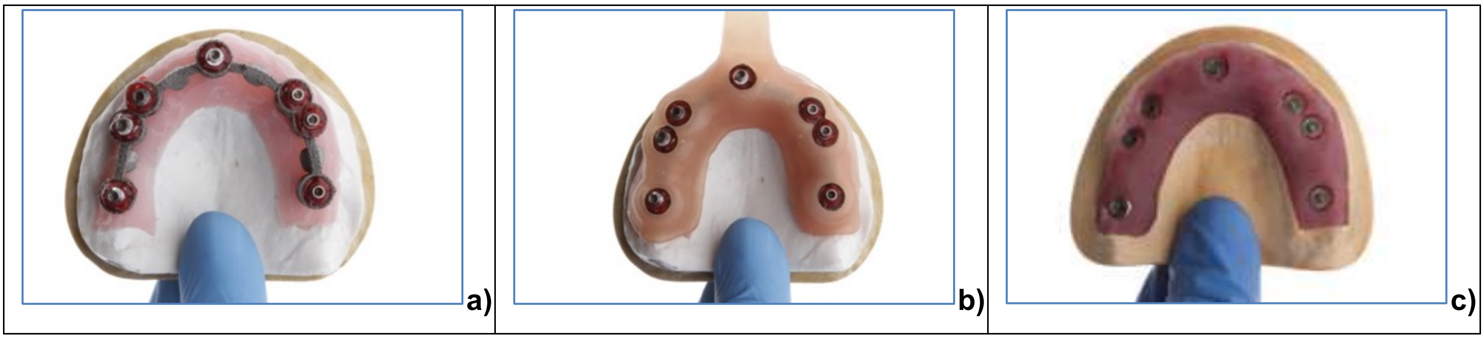


Figure 1 Complete edentulous maxillary definitive cast with 7 implant analogs.



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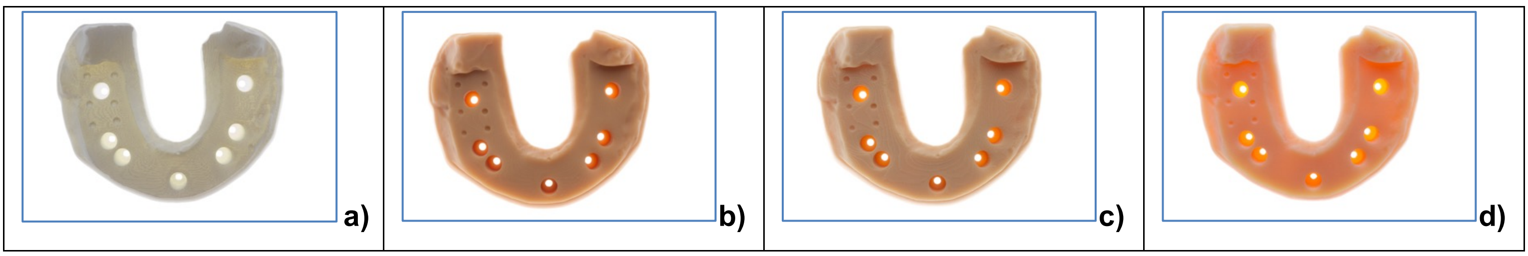

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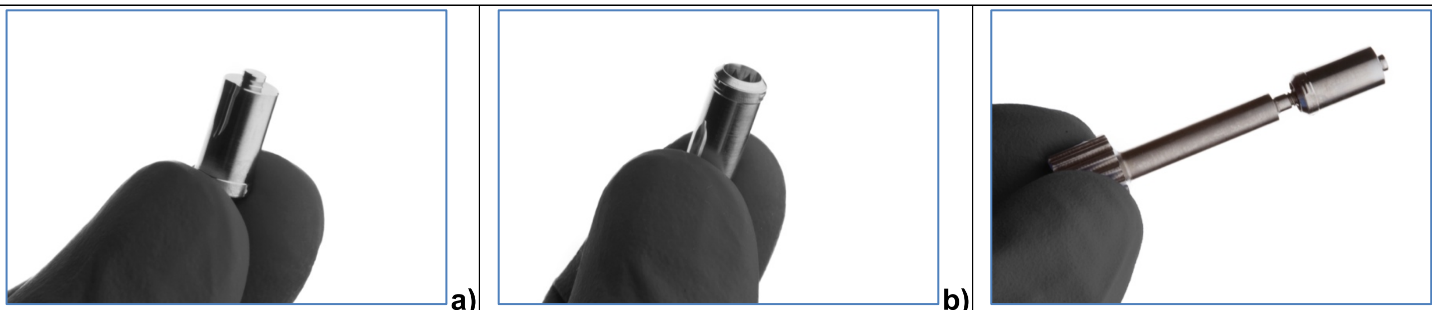
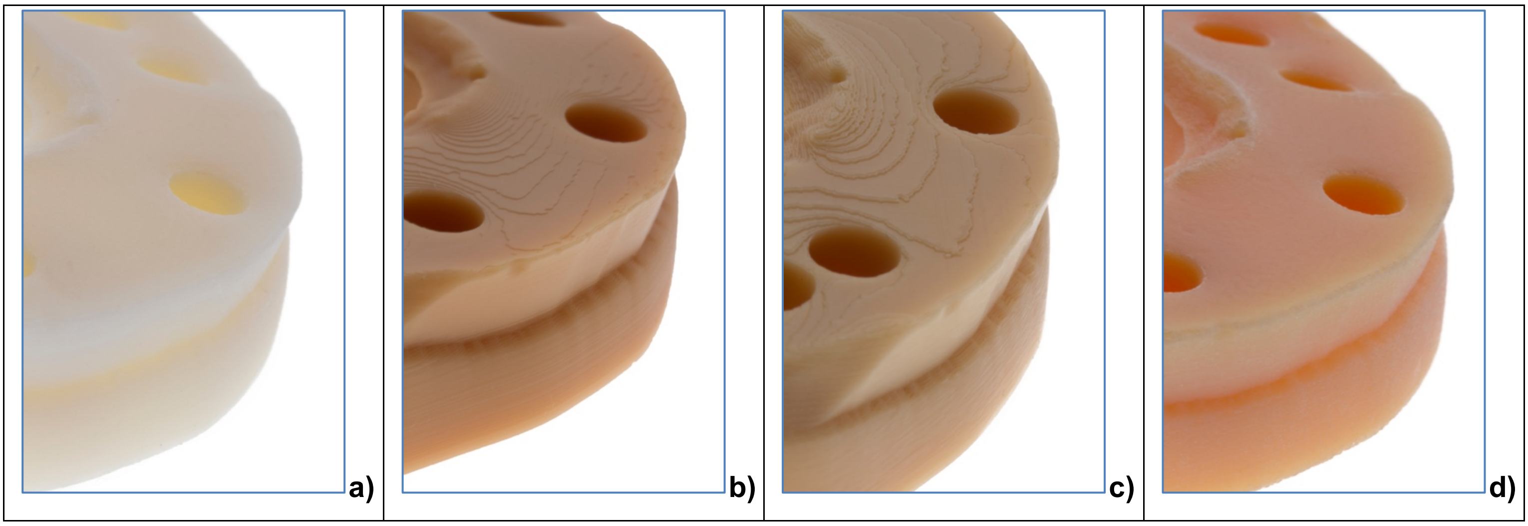


a) b) c)

Figures 4a-c. a) Apical view of the digital implant analog, **b)** Coronal view of the digital implant analog, **c)** Screwdriver to hold and position the implant analog on the printed cast.

a) b)

Figures 5a-b. a) Analysis of the implant analog position on the x-, y- and z-axis using a CMM machine, **b)** Best fit calculation using the specific software.



Figures 6a-d. Closer view of the surface texture of a specimen manufactured using **a)** MJP1, **b)** DLP, **c)** SLA, **d)** MJP2.